

## Restoration of Temperate and Boreal Forests

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### ABSTRACT

Throughout the boreal and temperate zones, forest restoration efforts attempt to counteract negative effects of conversion to other land use (afforestation and remediation) and disturbance and stress on existing forests (rehabilitation). Appropriate silvicultural practices can be designed for any forest restoration objective. Most common objectives include timber, wildlife habitat for game species, or aesthetics. Increasingly other objectives are considered, including carbon sequestration, biological diversity, non-game mammals and birds, endangered animals and plants, protection of water quality and aquatic resources, and recreation. Plantation forestry remains the most effective approach to restoration of forest cover to large areas, and recent trends toward more complex plantations are explored. Rehabilitation of degraded forests increasingly relies on re-establishing natural disturbance regimes and emphasizes "close-to-nature" approaches to regeneration and stand management. The objectives of this paper are to place forest restoration into the context of sustainable management and to present an overview of restoration activities in temperate and boreal forests.

### INTRODUCTION

Forest cover in populated areas of the world is in dynamic equilibrium with land cleared for agriculture and taken for urban uses. Forest cover has declined globally, from an estimated 6 billion ha of "original" forest extent to the present 3.45 billion ha (Krishnaswamy and Hanson 1999). The greatest loss in cover has occurred in Asia-Pacific, Africa, and Europe (all more than 60 percent loss of forest cover). Losses in North America are relatively low (25 percent), while Latin America (Central and South) has lost over 30 percent of the original forest cover (Figure 1). Market forces, changing trade policies, agricultural reforms, or conservation efforts drive conversion of cleared land back to trees. Nevertheless, the area in forest plantations is only 135 million ha, although increasing (Kanowski 1997).

Many areas remaining in forest cover are experiencing disturbances and stresses that negatively affect ecological stability (Larsen 1995) or maintain the forest in a condition that can be seen as unsustainable (Krishnaswamy and Hanson 1999). Global assessments of forest condition identify the factors causing loss of forest cover and degradation of remaining forests, including changing land use, increasing demand for fiber, and exogenous stresses such as global climate change and loss of biodiversity (Krishnaswamy and Hanson 1999, WRI 2000). Throughout the boreal and temperate zones, forest restoration efforts attempt to counteract these negative trends. The

objectives of this paper are to place forest restoration into the context of sustainable management and to present an overview of restoration activities in temperate and boreal forests. Plantation forestry remains the most effective approach to restoration of forest cover to large areas, and recent trends toward more complex plantations are explored. Rehabilitation of degraded forests increasingly relies on re-establishing natural disturbance regimes and emphasizes “close-to-nature” approaches to regeneration and stand management.

## TERMINOLOGY

What constitutes restoration can be confusing as the term is used indiscriminately. It is helpful to consider the dynamic relationship between degrading and restoring processes in light of two dimensions, changes in land cover, land use, or both. If we consider the undisturbed, idealized natural mature forest as a starting point (Figure 2), then conversions to other land uses such as agriculture or pasture are through deforestation. Relatively frequent but moderate disturbance (plowing, herbicides, grazing) maintains the non-forest cover.

Similarly, a change in both land cover and land use occurs when forests are converted to urban uses, flooded by dams, or removed along with topsoil/overburden in mining and extractive activities. Such drastic conversion usually involves severe disturbance and is maintained more or less permanently by structures more than by cultural activities (Figure 2).

Even-aged harvesting of mature forest in a sustainable manner is a change of land cover but not land use. A new, young forest will result from natural regeneration or by reforestation (i.e., planting trees in a cutover). Unsustainable harvesting without securing adequate regeneration, such as high-grading (many diameter-limit harvests or selective harvesting), degrades stand structure or diversity. Forest can also be degraded by pollutant loading, outbreaks of insects or diseases (especially exotics), invasion by aggressive exotic plants, or by disasters such as hurricanes or wildfires. In all these instances, intervention to restore species diversity or stand structure can be termed rehabilitation (Figure 2).

Given sufficient time and the cessation of disturbances, agricultural land as well as urbanized land will revert to forest, if that is the potential natural vegetation as set by climate. Abandonment and reversion to forests, albeit secondary or even degraded forest types, will be on a time scale of a few decades to centuries. Human intervention, however, can accelerate the reversion process. Afforestation of agricultural land may consist of simply planting trees, although techniques that are more intensive are available. Reclamation of urbanized land usually requires extensive modification. This may include stabilization of spoil banks or removal of water control structures, followed by tree planting. Because severe degradation may limit the possibilities for reclamation, this is sometimes called replacement (Bradshaw 1997).

Generally, restoration connotes some transition from a degraded state to a former “natural” condition. All the restorative activities described (reforestation, rehabilitation, afforestation, and reclamation) have been called forest restoration, although to the purist none would qualify as true restoration (Bradshaw 1997, Harrington 1999). In the narrowest sense, restoration requires a return to an ideal natural ecosystem with the same species diversity, composition, and structure as previously occurred (Bradshaw 1997) and as such is probably impossible to attain (Cairns

1986). Pragmatically, it would seem that the term forest restoration could be limited to situations where forest land use as well as land cover are restored (afforestation or reclamation), and rehabilitation to situations where structure or species composition of an existing forest is modified. This approach is adopted here.

## **THE SUSTAINABILITY CONTEXT**

### **The Continuum Model**

We view restoration as an element in a continuum model of sustainable forest management (Walker and Boyer 1993; Stanturf and others In press). The state of the forest ecosystem ranges from natural to degraded. Levels of state factors such as biomass or biodiversity in forests subjected to disturbance follow a degradation trajectory, which shape is characteristic to the state factor. At any point along the trajectory, recovery can be initiated once the stress or disturbance abates. The recovery pattern is divided into three levels: self-renewal, rehabilitation, or restoration. In the self-renewal phase, the forest can return to its original state, more or less, without human intervention in a relatively short time. Natural regeneration of forests managed for timber is an example of reliance on self-renewal processes. At intermediate levels of disturbance, it will take longer to recover naturally but the time required may be shortened by human intervention. One example might be rehabilitation by reforestation of forests consumed by wildfire. At their most degraded state, forests may recover naturally after a century or more, but in decades by human intervention.

The forest that results from restoration may never recover to the original state for all functions (see Harrington 1999 for a graphical representation of possible trajectories). Our usage of restoration differs from the otherwise very satisfactory terminology of Bradshaw (1997), as we do not accept the "ideal state" connotation he gives it. If we can move the ecosystem from the degraded to the natural state, we can then depend upon self-renewal processes in managing the resulting forest. How quickly the forest moves to the self-renewal phase is a function of the amount we are willing to invest to overcome the degraded conditions. This line may shift its vertical position depending upon available silvicultural techniques. The continuum model not only avoids the meaningless exercise of specifying an endpoint for restoration, but it offers a broader context for restoration on private land. Landowners with management objectives other than preservation are able to contribute to ecosystem restoration (Stanturf and others 1998a, Stanturf and others In press).

### **Common Challenges**

Appropriate silvicultural practices can be designed for any forest restoration objective. Most common objectives include timber, wildlife habitat for game species, or aesthetics. Increasingly other objectives are considered, including carbon sequestration, biological diversity, non-game mammals and birds, endangered animals and plants, protection of water quality and aquatic resources, and recreation. Different outputs may be sought for each objective. The timber management objective, for example, may be for sawlogs and veneer logs, or for pulpwood. Appropriate management, in particular rotation length, will vary according to the desired product size. Managing for wildlife may be the stated objective but different wildlife species or species group have different habitat requirements, from mature closed forests to early successional seres. Choosing the appropriate silvicultural techniques presents the challenge of managing for

apparently incompatible objectives. Slight modifications, however, may have negligible impact on outcomes or outputs for one objective but major effects on another objective. Clarity of objectives, combined with an adequate understanding of feasible goals developed from information on current conditions, allows the silviculturist to choose a silvicultural system that will maximize satisfaction of multiple objectives although no single objective will be optimized. Nevertheless, the chosen system may be adjusted to minimize impacts on other ecosystem functions, and many complementary benefits will be produced in addition to the primary benefit.

Three steps are key to planning forest restoration: (1) understanding current conditions (the given conditions, a starting point); (2) clarifying objectives and identifying an appropriate goal (the desired future condition); and (3) defining feasible actions that will move toward the desired condition. In most cases, the silviculturist has several options for intervening, as there are multiple silvicultural pathways toward the desired future condition. The choice of intervention affects the financial cost, the nature of intermediate conditions, and the time it takes to achieve the desired condition. It is imperative that silvicultural decisions are made with clear objectives in mind and with an understanding of the probability that a particular intervention will be successful.

There are many examples of forest restoration that can be classified as afforestation, reclamation, or rehabilitation (Table 1). The challenges of forest restoration in different countries are surprisingly similar (Kanowski 1997): overcoming site degradation or limitations; prescribing appropriate species; and applying cost-effective establishment methods. Several of these efforts are discussed in more detail below.

## **AFFORESTATION**

Forest restoration on land cleared for agriculture is widespread, often termed afforestation. Land was abandoned because of infertility, frequent flooding, or other site limitations. It should be self-evident that the first step in restoring a forest is to establish trees, the dominant vegetation. Although this is not full restoration in the sense of Bradshaw (1997), it is a necessary step and far from a trivial accomplishment (Stanturf and others 1998b, Stanturf and others In press). Nevertheless, many people object to traditional plantations on the grounds of aesthetics or lack of stand and landscape diversity. The correct ecological comparison, however, is between plantations and intensive agriculture, rather than between plantations and a mature natural forest (Stanturf and others In press). All forest alternatives provide at least some vertical structure, increased plant diversity, and some wildlife and environmental benefits. Kanowski (1997) argued for a dichotomy in concepts of plantations forests, between the traditional plantations organized for fiber production and more complex plantation systems that seek to maximize social benefits other than wood. Restoration goals can be met by developing a concept of complex plantations that retain the economic and logistic advantages of simple plantations.

### **Advantages of Simple Plantations**

Simple plantations are single purpose, usually even-aged monocultures that can produce as much as ten times greater wood volume as natural forests (Kanowski 1997). Simple plantations, nevertheless, provide multiple benefits when compared to alternatives such as continuous

agriculture; if managed well, they satisfy sustainability criteria. Significant advantages of simple plantations are that they easily can be established using proven technology, their management is straightforward, and they benefit from considerable economies of scale. If financial return is the primary objective of a landowner, simple plantations may be preferred and some restoration goals will be attained (Stanturf and others In press). Nevertheless, complex plantations can be established that provide greater social benefit at a reasonable cost, perhaps as little as 10 percent of timber returns (Kanowski 1997) or even at a net financial gain to the landowner (e.g., Stanturf and Portwood 1999).

### **Characteristics of Complex Plantations**

Objections to plantations are often cast in terms of aesthetics. The sharp boundary between a plantation and other land uses is objectionable, as is the uniformity of trees planted in rows. The sharp edges of plantations can be “softened” by fuzzy or curved boundaries, in order to integrate the plantation with other land uses. Where plantations are on small farm holdings, agroforestry systems of intercropping can blend land uses. Forested riparian buffers are established in agricultural fields to protect water quality by filtering sediment, nutrients, and farm chemicals, and they bar easy access by livestock to stream banks. Riparian buffers add diversity to the landscape and serve as wildlife corridors between patches of fragmented forests. In floodplain landscapes such as bottomland hardwoods, areas of permanently saturated or inundated soil (respectively, moist soil units and open water areas) are common and diversify the interior of plantations.

Several options are available to overcome the uniformity of rows. Perhaps the simplest technique is to offset the rows. Uniform spacing between rows and between seedlings within a row is common, resulting in a square pattern. Rows can be offset to produce a parallelogram instead of a square. Alternatively, plantations can be planned with a recreational viewer in mind so that the view from trails and roads is always oblique to the rows, thereby escaping notice. At any rate, once the canopy reaches sufficient height that ground flora and midstory plants can establish, most plantations take on the appearance of natural stands, at least to the casual observer.

A more serious objection to plantations is the lack of diversity, in terms of species composition and vertical structure. Essentially, simple plantations are not as diverse as natural stands, at least for many years. Foresters have devised several methods to establish multiple species stands. For example, planting several blocks of different species in a stand, or even alternate rows of different species is possible and creates some diversity at the stand level. Distribution, however, remains more clumped than would be typical of a natural stand.

Other methods are available, including nurse crops of faster growing native species (Schweitzer and others 1997) or exotics (Ashton and others 1997, Lamb and Tomlinson 1994). In this approach, there is no intention of retaining the nurse crop species throughout the rotation of the slower growing species (this could also be termed relay intercropping). While the nurse crop method has many advantages, and in the short-term provides species diversity and probably vertical structure, once the nurse crop is removed the residual stand may lack diversity. The challenge is to develop methods for establishing several species in intimate mixtures, such as would occur in a natural stand, but avoiding excessive mortality during the self-thinning or stem

exclusion stage of stand development. Such methods must account for the growth patterns of the species, relative shade tolerances, and competitive ability.

Vertical structure is an important feature of forests for wildlife (DeGraaf 1987, Twedt and Portwood 1997, Hamel and others In press). Early stages of stand development, whether in natural forests or plantations, are characterized by low light in the understory until crowns differentiate. In most restoration forests, little development of the understory and midstory occurs for many years. Annual disturbance while in agriculture removed buried seed and rootstocks of native plants and low light levels in the young forest preclude understory development from invaders. The manager can intervene to plant understory species; at present, little research affords guidance on methods, planting density, or probable success rates. As indicated above, relay intercropping provides vertical structure for a time. Natural dispersal into gaps can also encourage understory development, whether gaps are created by thinning or left during planting (Allen 1997, Otsamo 2000). The critical factor limiting understory development by natural invasion is whether there are seed sources for the understory plants within dispersal range (Chapman and Chapman 1999, Johnson 1988).

### **Afforestation of Bottomland Hardwoods in the Southern U.S.**

The Lower Mississippi Alluvial Valley (LMAV) has undergone the most widespread loss of bottomland hardwood forests in the United States (MacDonald and others 1979, Stanturf and others 2000). Besides the extensive loss of forest cover by clearing for agriculture, regional and local hydrologic cycles were drastically changed by flood control projects that separated the Mississippi River and its tributaries from their floodplains. Deforestation and drainage resulted in a loss of critical wildlife and fish habitat, increased sediment loads, and reduced floodwater retention. Restoring these floodplain forests is the subject of considerable interest and activity (Sharitz 1992, King and Keeland 1999, Stanturf and others 2000).

Restoration on the LMAV is driven primarily by actions on federal land and by federal incentive programs, although states have their projects on public land (Newling 1990; Savage and others 1989). Current plans for restoration on public and private land suggest that as many as 200,000 ha could be restored in the LMAV over the next decade (Stanturf and others 2000).

The dominant goal of all restoration programs in the LMAV, whether on public or private land, has been to create wildlife habitat and improve or protect surface water quality (King and Keeland 1999). In practice, this means afforestation of small areas (usually no more than 300 acres) within a matrix of active agriculture. While we know how to afforest many sites (Stanturf and others 1998b), recent experience illustrates the difficulty of applying this knowledge broadly (Stanturf and others In press).

Afforestation of bottomland hardwoods is a process where something can go wrong at any of several steps (Gardiner and others In press). The most critical step is properly matching species to site, particularly to hydroperiod. Few species can tolerate continuous flooding. Even those few that can withstand extended soil saturation and root anoxia cannot tolerate submersion of all their leaves. Most flooding tolerant species can be planted on drier sites but not the reverse (Stanturf and others 1998a). Soil physical conditions, root aeration, nutrient availability, and moisture availability are other important site factors to consider.

Restoration on public land in the LMAV follows an extensive strategy of low cost per ha planting or direct seeding of heavy-seeded species of value to wildlife such as oaks. It relies on native species, planted mostly in single-species blocks within plantations containing three or more species. Choice of species to plant is guided by tolerance to flooding and soil characteristics. Hard mast producers such as the oaks (*Quercus* spp.) are favored for their wildlife value and because they are the most difficult to obtain by natural processes. Oaks are planted on wide spacing (3.45 m by 3.45 m) as 1-0 bareroot seedlings or direct-seeded as acorns on 1 m by 3.45 m spacing (to account for lower survival). Wind and water are relied upon to disperse light-seeded species such as ash (*Fraxinus* spp.), elm (*Ulmus* spp.), sycamore (*Platanus occidentalis*), sweetgum (*Liquidambar styraciflua*), and maple (*Acer* spp.) (Stanturf and others 1998). The light-seeded species are needed for richness, stocking, and to create forested conditions (Haynes and others 1995).

The extensive strategy that predominates on public land has shaped the federal programs aimed at private land. The appropriateness of this strategy for private land has been questioned from several perspectives (Stanturf and others In press). First, wind and water dispersal of light seeded species to these small, isolated tracts is reliable only when natural seed sources are within 100 m (Allen 1990, 1997). Failure to fill between the planted oaks means incomplete site occupancy by trees, lower species richness, and longer time needed to provide structural diversity. Second, more intensive strategies are available that provide wildlife benefits and restore forested wetland functions quicker. Many wildlife species at risk are those that require forests of complex structure. Extensive plantings, even if fully successful, require 60 years or more to attain a desirable structure (King and Keeland 1999, Twedt and others 1999). Third, the stocking that results from successful restoration under federal cost-share programs (i.e., 309 stems per ha at age 3) will not be sufficient to support commercial timber production. The lack of merchantable volume in these understocked stands not only will constrain timber management but also will limit stand manipulation for wildlife habitat, aesthetics, or forest health. Fourth, the ability to sequester carbon will be significantly lower. Interest is increasing in afforestation to obtain carbon credits under the Kyoto Protocol (Schlamadinger and Marland 2000) and the critical period for credits is between 2008 and 2012, very early in the life of stands planted now.

Strategies that are more intensive for quickly establishing closed canopy forests are available, albeit at higher initial costs than the extensive plantings. For example, a manager can establish a closed canopy forest 10 m or taller in three years, using fast growing native species such as Eastern cottonwood (*Populus deltoides* var. *deltoides*). One or two years after planting, this cottonwood nurse crop is established and slower growing species of oak can be interplanted between every other row. Later, the manager may intervene to shape stand structure and composition of the stand as it develops. Possibilities include harvesting the cottonwood at age 10, in the winter to maximize sprout regrowth and afford the manager a second coppice rotation of the cottonwood, or in the summer to minimize cottonwood sprouting and release the oak seedlings (Schweitzer and others 1997). The full benefits of this interplanting technique are being investigated but observations in operational plantings indicate that significant wildlife benefits are realized within five years (Twedt and Portwood 1997).

### **Afforestation of Broadleaves in the Nordic Countries**

The term “forest restoration” covers very different silvicultural challenges in the Nordic countries. In Iceland, afforestation is attempted on barren land degraded by overgrazing. Special effort is made to restore birch woodlands, which covered more than 25 percent of the land area at the time of settlement in the 10<sup>th</sup> Century (Sigurdsson, 1977). Contrary to the Icelandic situation, afforestation efforts in the other Nordic countries and Estonia occurs on fertile farmland. Aims of afforestation are rather different within and between the countries. In Finland, Sweden, and Norway the expected extent of afforestation is rather limited and serves mainly as an alternative land use to small scale and inefficient agriculture. In Estonia, many small farms have been turned over to the descendants of the former owners. They have no experience or expertise with farming, so forestry may be an attractive, low-cost land use alternative. Consequently, a significant increase in forestland on abandoned farmland is expected in Estonia. In Denmark, the goal of the afforestation programme is to double the forested area within one tree generation (approximately 100 years). The several aims of this program include:

- Increased concern for sustainability, nature conservation and biodiversity,
- Protection of ground water resources,
- Improvement of recreational values of the landscape, and
- Reduction of the subsidised agricultural production.

Afforestation of broadleaves is preferred, although conifers are allowed under certain conditions. Typically broadleaved seedlings are planted at densities up to 5,000 per ha. There must be a minimum of 2,500 to 4,000 saplings surviving at 8 to 12 years after planting. Additional subsidies are paid in Denmark for pesticide-free afforestation, fencing, and income compensation. Direct seeding of oak is gaining popularity on farmland in southern Sweden and Denmark (Madsen and others In press). Costs are 30 percent to 50 percent of planting seedlings and reliable on bare farmland without rodents.

## REHABILITATION

Degradation of existing forests occurs from anthropogenic and natural disturbance. By degradation, we mean loss of species, simplification of stand structure, or invasion by exotic organisms. The first step in rehabilitation is to identify the cause of site or stand degradation. Stand degradation from high grading or fire suppression may be remedied through vegetation manipulation alone. Alteration of the site by changed hydroperiod, atmospheric deposition, or catastrophic fires poses broader questions. Can the pre-disturbance conditions be restored or the effects of alteration somehow mitigated? Should the rehabilitation effort target a different vegetation assemblage, perhaps one more adapted to present conditions? For example, hydroperiod alterations caused by flood control projects, dams, or highway construction tend to be irrevocable, at least in the short-term. Flooding caused by beaver dams, however, can be reduced by removing the dam but continued management of beaver population levels will be required to avoid recurring problems. The guiding principle for silviculturist should be to rehabilitate or restore in accordance with existing conditions, unless alteration is feasible, affordable, and within the control of the silviculturist.



Often the current stand is so degraded that true site potential, in terms of species composition and productivity, is masked. On the other hand, one must be careful to avoid attributing a higher potential than is warranted and mistakenly blaming "degradation" for conditions on an inherently poor site. Site potential refers to the combination of relatively unchanging physical factors which affect species composition and stand vigor. These are not immutable, however, and changes in hydroperiod especially can degrade a site. On the other hand, selectively logging the biggest and best trees of a few species may degrade the stand without lowering the potential of the site. A site's potential, and whether it has been degraded, sets limits on what can be achieved by silvicultural intervention. Site potential also determines the general direction of stand development and the likely outcome of any major disturbance that replaces the existing stand.

The stability of forests can be expressed in terms of resistance and resilience of the forest ecosystem (Larsen 1995). Poor resistance may be expressed as susceptibility of the forest to damage or destruction by strong winds, drought, fire or a complex of factors. Poor resilience can be characterized as difficulty in regaining pre-disturbance conditions, leading to regeneration problems. For example, traditional forestry in northern Europe has mainly concentrated on growing conifers for timber and pulp. Over the past two decades, concern has increased for ecological stability, nature conservation, and sustainable land use. One response to this concern is often termed close-to-nature silviculture, which is characterized by greater use of broadleaved species, less reliance on artificial regeneration and plantation culture, and attempts to restore forests that are more diverse. In many European countries, rehabilitation of largely coniferous plantations to mixed deciduous woodlands is aided by stand disturbing windstorms.

### **Rehabilitation of Broadleaved Woodlands in Northern Europe**

Traditional forestry in northern Europe has mainly concentrated on growing conifers for timber and pulp in both the boreal and the nemoral zone. During the past two decades, increased public concern for ecological sustainability, nature conservation and sustainable land use, along with economical constraints and reduced softwood timber prices, has led to increased focus on the use of broadleaved species and close-to-nature forest management. The more diverse and multifunctional aims of forestry have emphasised the needs for the forests to be flexible with respect to future outputs as wood and non-wood products and values. Additionally, the importance of such flexibility is underscored by the long production periods in European forestry, where rotation lengths usually range between 50 and 120 years. The problem is that nobody can precisely predict what will be the main role of the future forests.

Presently coniferous plantations are being transformed into broadleaved stands, particularly on the better soils in the deciduous zone of south Sweden and Denmark; in Bavaria in Germany; in England; and in Ireland. Today, the main species in coniferous plantations are Norway spruce (*Picea abies*), Sitka spruce (*Picea sitchensis*), and pines. Norway spruce is outside or on the edge of its natural range in Denmark and south Sweden, and may be off-site in other areas. The conifers were initially planted due to high production value and lower cultivation costs. However, they have shown poor wind stability and health on many sites. Catastrophic winds not only destroy the existing forests, but also create regeneration problems over large areas.

Planting broadleaves following a clearcut or under conifer shelterwood is common. Species typically include beech (*Fagus sylvatica*), pedunculate oak (*Q. robur*), ash (*Fraxinus excelsior*),

and basswood (*Tilia cordata* or *T. platyphyllos*). Direct seeding oaks and beech into shelterwoods and clearcuts has been attempted with some success in Germany, Sweden, and Denmark. Catastrophic windstorms in recent years have given impetus to finding reliable, low-cost alternatives such as direct seeding. On oceanic islands such as Ireland, however, shelterwoods are uncommon as frequent high winds make the risk of blowdown of the residual stand high.

### **Rehabilitation of Shortleaf Pine Woodlands in the Interior Highlands, United States**

The Interior Highlands refers to the broad plateaus and low mountains called the Ozark Plateaus of the Boston Mountains and the Ouachita Mountains. The two areas are separated by a structural trough occupied by the Arkansas River (Walker 1994). Soils of the Ozark Plateaus are formed mostly on limestone and dolomite, while those of the Ouachita Mountains are formed on sandstone and shale. High insolation due the prevailing east-west orientation of the Interior Highlands, plus erratic rainfall and high temperatures, limit the forest over much of the area to those types adapted to poor soils and dry sites. Extensive pure stands of shortleaf pine (*Pinus echinata*) have been maintained in public and industrial management in the Ouachita Mountains (Walker 1994), although loblolly pine (*P. taeda*) is managed intensively in plantations. Hardwoods encroach under the pine, and they will capture the site when the sub-climax pines are eliminated, leading to pine-hardwood mixtures.

Prior to European settlement of the region, pines maintained dominance by their tolerance to periodic fire. In the Ouachita Mountains, stands were dominated by pines, primarily shortleaf (*Pinus echinata*) with a minor hardwood component in the overstory, mostly *Quercus* spp. A native herbaceous understory dominated by bluestem grasses was maintained by fire. Soils are generally moderately deep to deep (50 cm to 150 cm) and frequently classified as Typic Hapludults. Shortleaf pine site index on the deeper soils ranges between 18 m and 21 m at age 50. On soils with depths of less than 50 cm, site index is typically between 12 m and 15 m. On steep upper slopes, site index can be as low as 9 m (Guldin 1986; Graney 1986). Most of these soils have moderate to severe erosion potential, which can be predicted from rock content; the greatest potential is in soils of less than 15 percent rock (Luckow 1998).

Restoration research is beginning in this region, designed to mimic pre-settlement conditions. Experimental treatments include commercial thinning of the overstory, with residual pines and scattered hardwoods in the main canopy at lower basal areas than in the controls. Total basal area of the restoration treatment is approximately half the controls ( $15 \text{ m}^2 \text{ ha}^{-1}$  versus  $27 \text{ m}^2 \text{ ha}^{-1}$ ). The predominantly hardwood midstory and understory is removed by hand labor (chainsaws or hand tools). Burning is conducted at 2 to 5 year intervals for 10 years, during the dormant or growing season, with moderate intensity fires. Over time, sustainability will be achieved by an area-based approach using even-aged reproduction methods, primarily two-aged shelterwood. The resulting stands will be open and park-like. Approximately 63,000 ha of shortleaf pine-bluestem ecosystems are planned to be restored on the Ouachita National Forest in Arkansas and Oklahoma.

### **BENEFITS OF RESTORATION**

The benefits of restoration are usually identified in terms of government priorities or social benefits; seldom are the diverse objectives of landowners recognized (but see Selby and Petäjäisto 1995). In most market economies where rights and obligations of ownership rest with private landowners, what is appropriate for public land may not be the most attractive restoration option for private landowners (Stanturf and others In press). Nevertheless, there can be considerable overlap in the expected benefits to society and the affected landowner. The array of possible objectives can be illustrated with a limited set of management scenarios (Table 2). For simplification, three scenarios are presented: production forest, conservation forest, or preservation forest. The production forest option can be further divided into low versus high intensity management.

Benefits are comprised of financial, recreational, and environmental outcomes. Because cash flow is important to many landowners, and the adjustment from annual to periodic income is often cited as a barrier to afforestation, financial benefits must be considered as both short-term and long-term (Amacher and others 1998, Niskanen 1999). Recreational benefits are hunting and non-consumptive benefits such as bird watching or hiking. Environmental benefits are separated into conservation practices (such as those installed to control soil erosion and protect water quality or enhance wildlife habitat) and land retirement, where there is no on-going management activity.

### **Financial Benefits**

Financial returns from active management (production or conservation forests) are substantial relative to the preservation or no-management scenario. Fiber production will drive expansion of plantations in many parts of the world (Carneiro and Brown 1999). Other income can be realized by some landowners from hunting leases and potentially from carbon sequestration payments (Barker and others 1996). While there is considerable uncertainty over the accounting for carbon credits under the Kyoto Protocol, there seems to be agreement that afforestation will be eligible for offset credit (Schlamadinger and Marland 2000). Current projections in the United States for the value of a carbon credit are on the order of \$2.72 to \$4.54 per ton of CO<sub>2</sub> sequestered, but the value is much higher in Europe. In Norway, for example, there is already a carbon tax on gasoline equivalent to \$49 per ton CO<sub>2</sub> (Solberg 1997). Estimates from economic models suggest that a carbon tax of \$27 to \$109 per ton CO<sub>2</sub> would be necessary to stabilize global emissions at the 1990 level (Solberg 1997). Under these conditions, growing biomass for fuel would become an attractive alternative to fossil fuel because biofuels have no net impact on global carbon levels.

### **Recreational Benefits**

The primary recreational benefits assumed in the examples are from creating and enhancing wildlife habitat. Not all wildlife species require the same kind of habitat, so for simplicity the expected benefits can be separated into recreational hunting by the landowner (rather than lease fees) and non-consumptive wildlife activities, such as bird watching or simply the existence value of wildlife to the landowner.

### **Environmental Benefits**

Water quality benefits of afforestation accrue from reducing soil erosion (Joslin and Schoenholtz 1998), and filtering, retaining, and assimilating nutrients and farm chemicals from surface runoff

and groundwater (Huang and others 1990). Greater water quality benefit will be derived from forested riparian buffers. Planted forested buffer strips in an agricultural landscape are uncommon, although several studies have examined the filtering action of natural forested riparian zones (Cooper and others 1987, Cooper and Gilliam 1987, Lowrance and others 1983, Lowrance and others 1984a and b, Lowrance and others 1986, Peterjohn and Correll 1984, Todd and others 1983). These studies were summarized by Comerford and others (1992) who concluded that buffer strips are quite effective in removing soluble nitrogen and phosphorus (up to 99 percent) and sediment. The efficiency of pesticide removal by forested buffer strips has been examined in some environmental fate studies that concluded that buffer strips 15 m or wider were generally effective in minimizing pesticide contamination of streams from overland flow (Comerford and others 1992).

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Table 1—Examples of forest restoration efforts in various parts of the world

Type of restoration	Region	Former condition	Restored condition
Afforestation	Lower Mississippi Alluvial Valley, USA <sup>1</sup>	Agriculture	Bottomland hardwoods
Afforestation	Nordic Countries <sup>2</sup>	Agriculture	Hardwoods, sometimes Norway spruce
Afforestation	Tropical Countries <sup>3</sup>	Agriculture	Exotic and native hardwoods
Afforestation	Venezuela	Cerrado	Caribbean pine
Afforestation	Iceland <sup>4</sup>	Eroded grazing land	Birch, lupine/birch
Reclamation	Everywhere	Mined land	Various
Reclamation	Asia <sup>5</sup>	Shrimp ponds	Mangrove
Reclamation	Ireland	Mined peatland	Sitka spruce, various hardwoods
Reclamation	India <sup>6</sup>	Saline and sodic soils	Eucalyptus spp., Acacia spp., other native spp.
Rehabilitation	Southeastern US <sup>7</sup>	Loblolly pine plantations	Longleaf pine woodlands
Rehabilitation	Interior highlands, Southeastern US	Shortleaf pine/hardwood forests	Shortleaf pine/bluestem grass woodlands
Rehabilitation	Northern Europe <sup>8</sup>	Norway spruce plantations	Oak or beech woodlands
Rehabilitation	England and Scotland	Spruce or pine plantations	Mixed woodlands

<sup>1</sup> Allen 1990, 1997; Gardiner and others In press; Hamel and others In press; Newling 1990; Savage and others 1989; Schweitzer and others 1997; Sharitz 1992; Stanturf and others 1998a, b; Stanturf and others 2000; Stanturf and others In press; Twedt and Portwood 1997; Twedt and others 1999.

<sup>2</sup> Madsen and others In press.

<sup>3</sup> Ashton and others 1997; Chapman and Chapman 1999; Fisher 1995; Islam and others 1999; Knowles and Parrotta 1995; Lamb and Tomlinson 1994; Ohta 1990; Otsumo 2000; Parrotta 1992; Parrotta and others 1997.

<sup>4</sup> Madsen and others In press; Sigurdsson 1977.

<sup>5</sup> Burbridge and Hellin In press.

<sup>6</sup> Whalley 1988.

<sup>7</sup> Walker and Boyer 1993.

<sup>8</sup> Madsen and others In press.

Table 2. Expected benefits from afforestation, depending upon objectives and management intensity.

Scenario	Expected Benefit Level					
	Financial		Recreational		Environmental	
	Short-term	Long-Term	Hunting	Non-Consumptive	Conservation Practices	Land Retirement
Production Forest-High Intensity (Short Rotation: Pulpwood, Fuelwood)	High	High	High	Medium	Medium	No
Production Forest-Low Intensity (Long-Rotation: Timber, Wildlife)	Medium	High	High	High	High	No
Conservation Forest	Low	Medium	High	High	High	Low
Preservation Forest	Low to No	No	Low	Medium	Medium	High

Figure 1. Loss of original forest cover, from 6 billion ha to 3.45 billion ha.

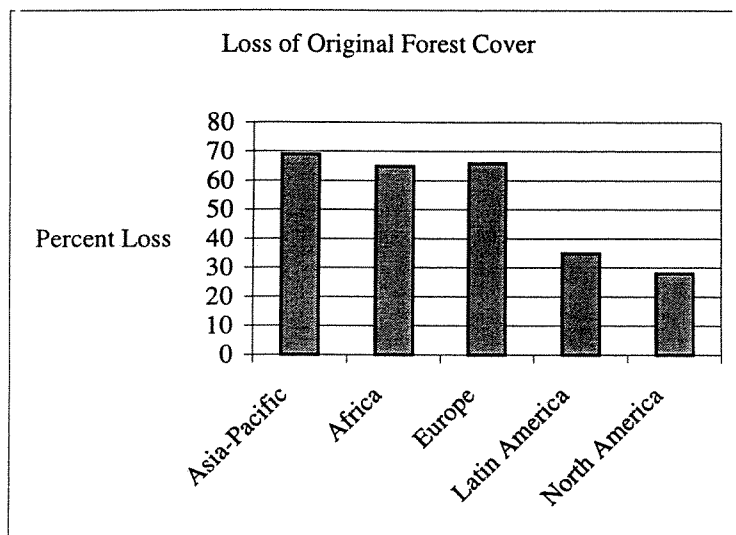


Figure 2. The terminology of forest restoration is best viewed in terms of land use as well as land cover change.

